Certification Methodology & Tools

Fred Proctor and David Hamilton

NASA Langley Research Center

Hampton, Virginia

WxAP Annual Review
Las Vegas, NV
June 2-4, 2004

Outline

Presented by Fred Proctor:

- Overview
- Turbulence Classification
- Hazard Metrics
- Data Sets
- Hazard Analysis Tools

Presented by David Hamilton:

- Tool Set Demonstration
- Summary

Turbulence Classification

- Convectively Induced Turbulence (CIT)
  - Occurs within proximity of convective clouds
  - Primary focus of TPAWS project
- Clear Air Turbulence (CAT)
- Mountain Wave Induced Turbulence
- Boundary Layer Turbulence

Turbulence Classification (cont.)

- CIT primary cause of in-flight injuries
- Kaplan et al. determined from NTSB reports
  - 82% of turbulence events with injuries within vicinity of convective build-ups
  - Clear Air Turbulence (CAT) - 16% of turbulence events
  - Mountain Wave Induced Turbulence - 2% of events

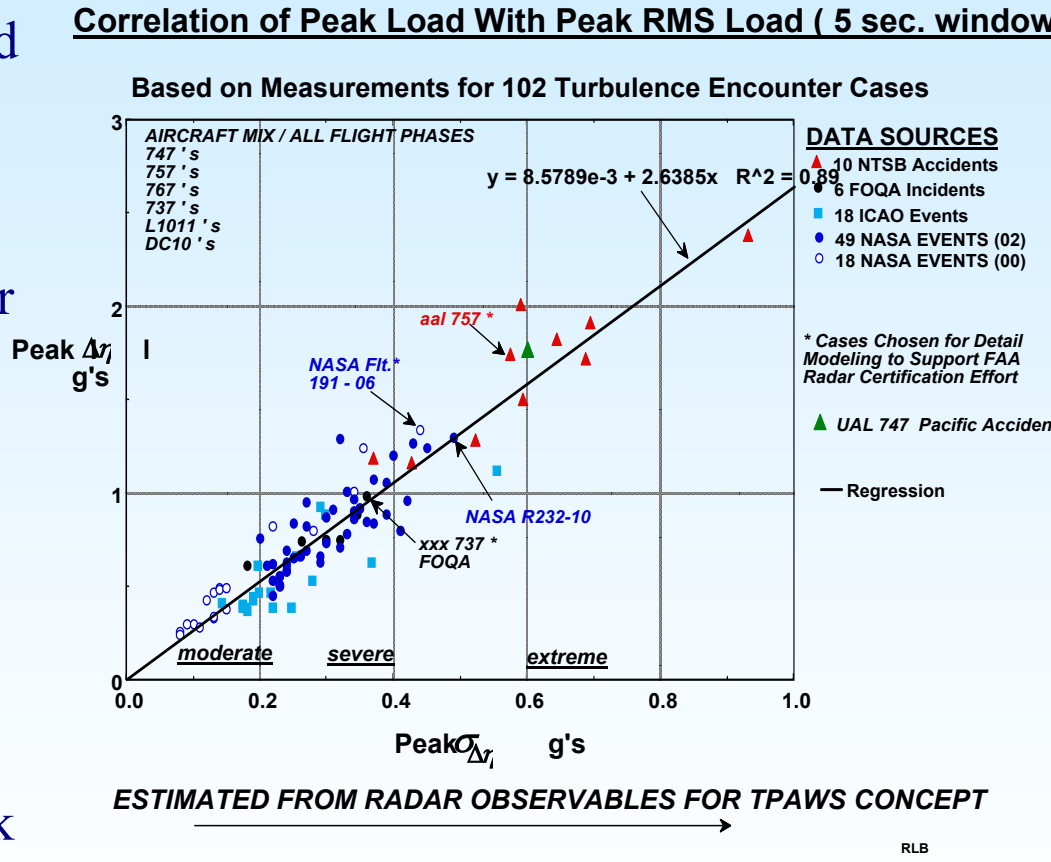
Kaplan, M.L., Huffman, A. W., Lux, K. M., Charney, J.J., Riordan, A.J., and Lin, Y.-L., "Characterizing the Severe Turbulence Environments Associated With Commercial Aviation Accidents---Part I: 44 Case Study Synoptic Observational Analyses," NASA/CR-2002-211918, August 2002, 57 pp.

Turbulence Classification (cont.)

- Convectively Induced Turbulence (CIT)
  - Aircraft encounters are usually unexpected and of short duration
  - Encounters occur when:
    - aircraft skirt around high reflectivity regions to minimize deviation from flight plan
    - convection appears invisible or benign from aircraft's radar
    - storm tops unexpected rise into the aircraft's flight path
    - aircraft are inadvertently vectored into convection by ATC
  - Intensity of turbulence not correlated with level of radar reflectivity
  - Many events are detectable with aircraft radar

Hazard Metrics

- RMS Normal Load
  - Can be obtained from measured aircraft dynamic loads
  - Can be estimated from vertical velocity
  - May be estimated with Doppler radar if sufficient radar reflectivity exist
- Peak Normal Load
  - Occurs over a small time and length scale
  - Almost impossible to measure with predictive sensors
  - Magnitude proportional to peak RMS normal load



Aircraft Normal Loads

- Function of:
  - Along track gradients of vertical velocity
  - Scales of atmospheric motion between ~4km – 40m
  - Aircraft type
  - Aircraft weight
  - Altitude (air density)
  - Airspeed
- Also can be induced by aircraft maneuvers

TPAWS Tool Set

- **Model Data Sets**
- **Hazard Tables**
- **Hazard Metrics**
- **ADWRS**
- **Scoring Tools**

– **for testing airborne systems that are intended to detect turbulence hazard associated with atmospheric convection**
– **useful for evaluation of detection system**
– **available for anticipated FAA certification activity**

Tool set components, reports, and data set descriptions can be found on TPAWS web site: http://tpaws.larc.nasa.gov/

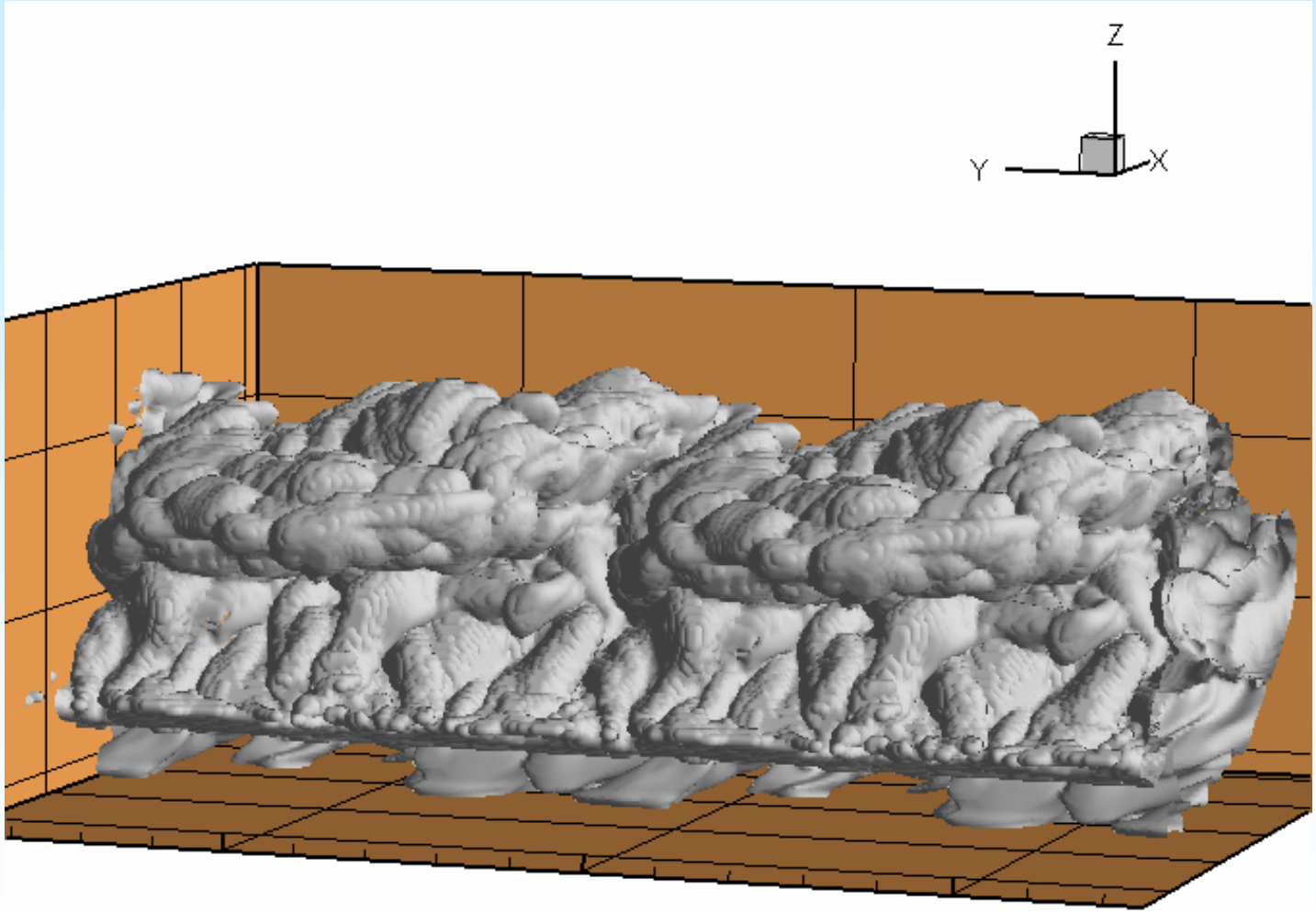
TPAWS Model Data Sets

- **Event 191-06**
  - Severe turbulence encountered at 10.3 *km* AGL on 14 Dec 2000 during NASA's TPAWS flight tests. Event associated with overshooting tops of a convective line across FL panhandle.
  - Data set contains severe turbulence in regions of low radar reflectivity.
- **Dickinson, ND**
  - Severe turbulence encountered by a commercial B-757 as it reportedly flew over the tops of thunderstorms on 10 July 1997.
  - Data set contains severe turbulence in regions of low and moderate reflectivity.

Model Data Sets (cont.)

- **FOQA - Wilmington**
  - Severe turbulence encountered by a commercial B-737 at 2.3 *km* AGL near Wilmington, DE, while on descent. Airliner vectored by ATC into leading edge of shallow convection with tops between 5-6 km.
  - Data set contains patches of moderate to severe turbulence in regions of low radar reflectivity.
- **232-10**
  - Severe turbulence encountered by NASA's B-757 during spring 2002 flight test. Encounter occurred in IMC conditions with "ship's radar" displaying black and green. Exemplifies operational environment in which accidents occur due to turbulence.
  - Data set contains severe turbulence associated with low-reflectivity regions of rising cloud tops.

TASS Simulated Cloud – FOQA



Tool Set Component: Hazard Analysis Algorithms

- **Estimates of Hazard from Model Wind Fields needed for Truthing Radar Simulations**
- **RMS Normal Load obtained from σ_w using a moving box and hazard tables.**
- **Hazard tables based on aircraft:**
  - **Type**
  - **Weight**
  - **Altitude**

Moving Box Method

For any horizontal plane in the model data set, σ_w is computed using a moving box as:

$$\sigma_w(x,y)=\left[\frac{1}{L_xL_y}\int_{x-\frac{L_x}{2}}^{x+\frac{L_x}{2}}\int_{y-\frac{L_y}{2}}^{y+\frac{L_y}{2}}\{w(x',y')-\overline{w}(x,y)\}^2\,dx'dy'\right]^{\frac{1}{2}}$$

where the averaging interval is $L_x=L_y=t_1 V_a$, V_a is airspeed, t_1=5 *sec*, *w* is vertical wind, and the box-averaged w is:

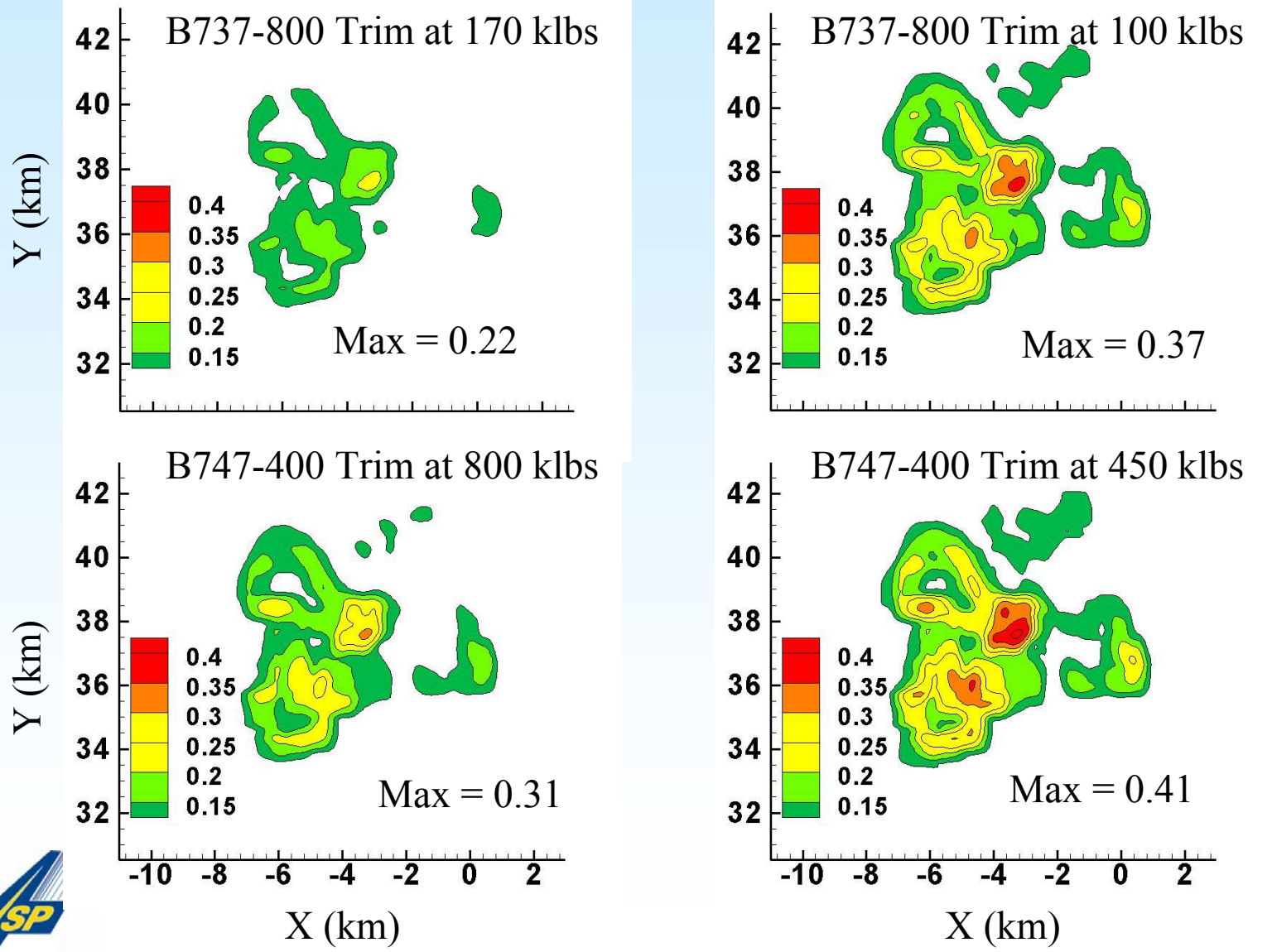
$$\overline{w}(x,y)=\frac{1}{L_xL_y}\int_{x-\frac{L_x}{2}}^{x+\frac{L_x}{2}}\int_{y-\frac{L_y}{2}}^{y+\frac{L_y}{2}}w(x',y')dx'dy'$$

Moving Box Method

- Easy to apply to model data sets
- Diagnosed from model vertical wind field
- Utilizes Table ‘look-up’ for aircraft
- Maps hazard field on a cross sectional plane
- Diagnosed Hazard dependent upon aircraft type and weight.

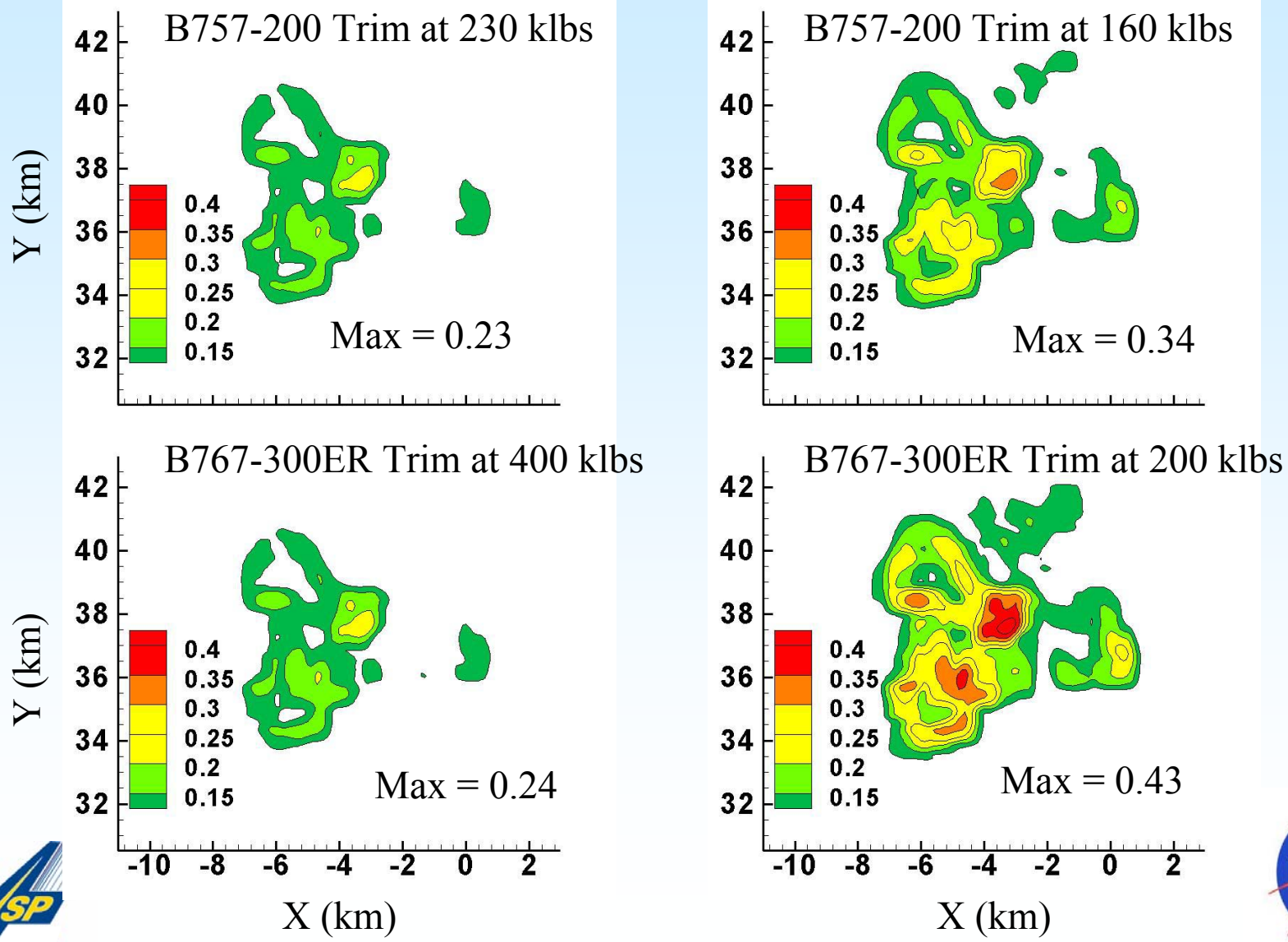
Horizontal Cross-Section of 100 m FLR 191-6 Data Set

RMS acceleration from $\hat{\sigma}_w$ at 10.3 km Elevation



Horizontal Cross-Section of 100 m FLR 191-6 Data Set

RMS acceleration from $\hat{\sigma}_w$ at 10.3 km Elevation

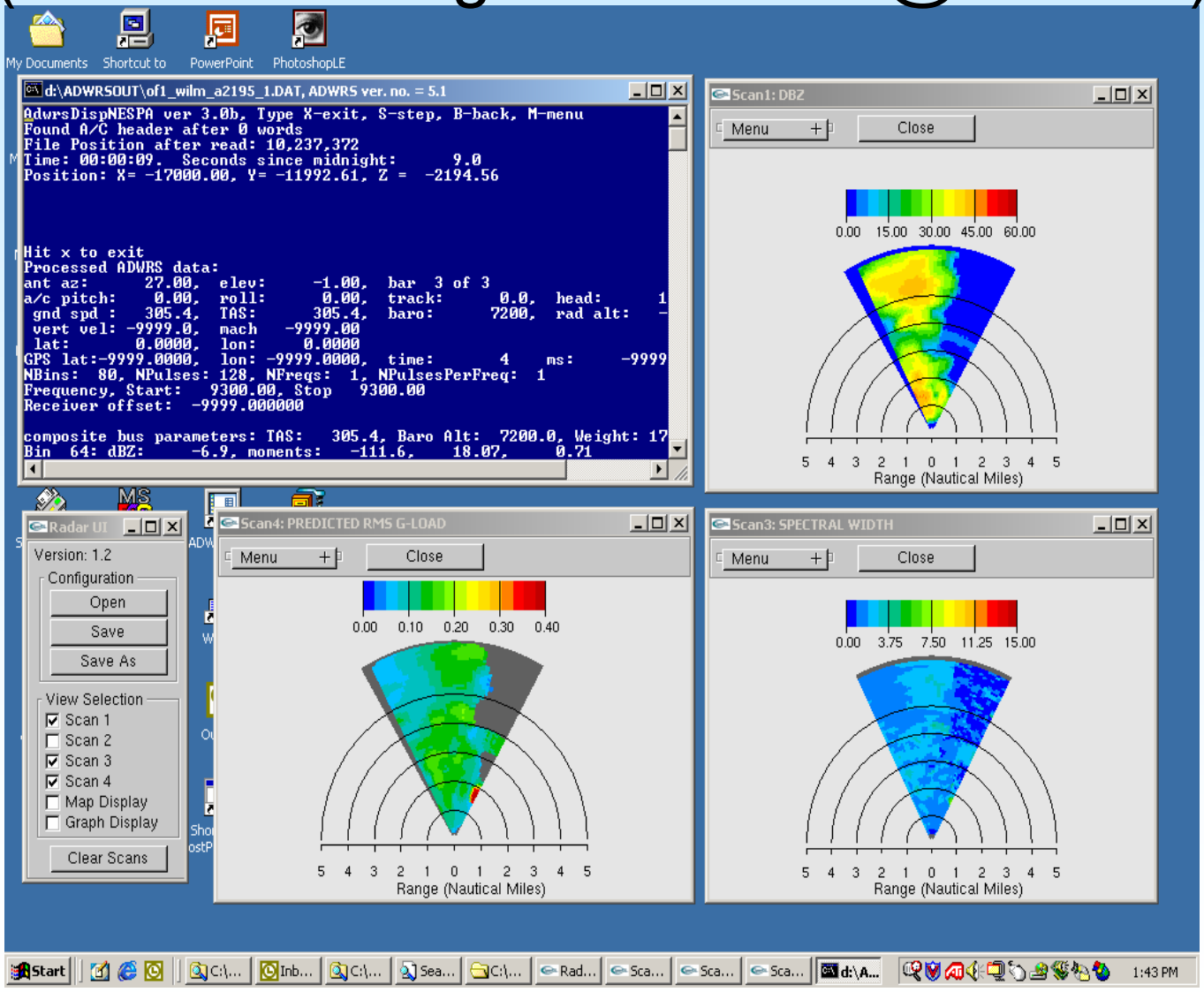


ADWRS – Airborne Doppler Weather Radar Simulation

A comprehensive simulation of an airborne Doppler weather radar that generates Doppler radar IQ data and associated aircraft data from input weather data files and user defined flight paths.

Example of ADWRS Post-processor Display

(FOQA-Wilmington DE data @ 2.3 km)



FHP/DWH

Tool Set Demonstration

Demonstration Outline

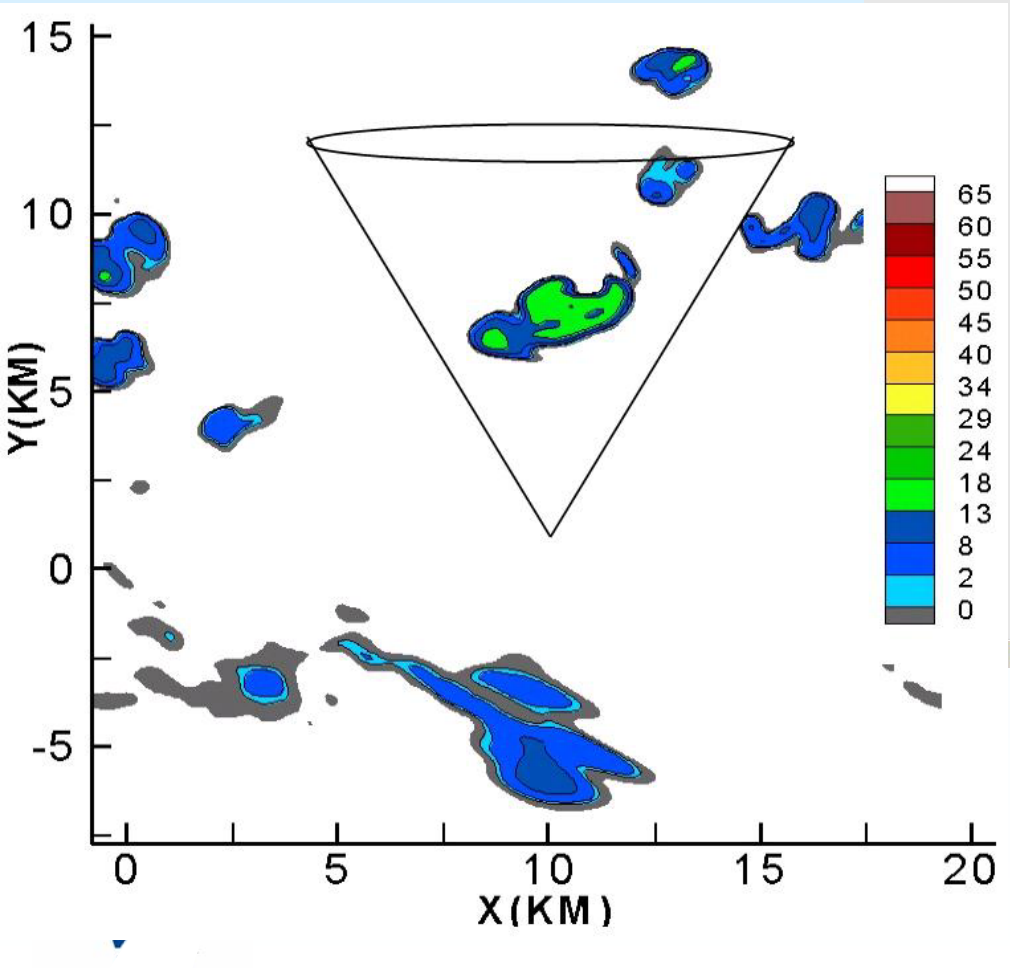
- ADWRS applied to TPAWS data sets
  - 232-10
  - FOQA-Wilmington
  - 191-06
- Hazard predictions assume NESPA module
- Comparison with Moving-Box Method
- Hazard prediction sensitivity to airspeed and weight

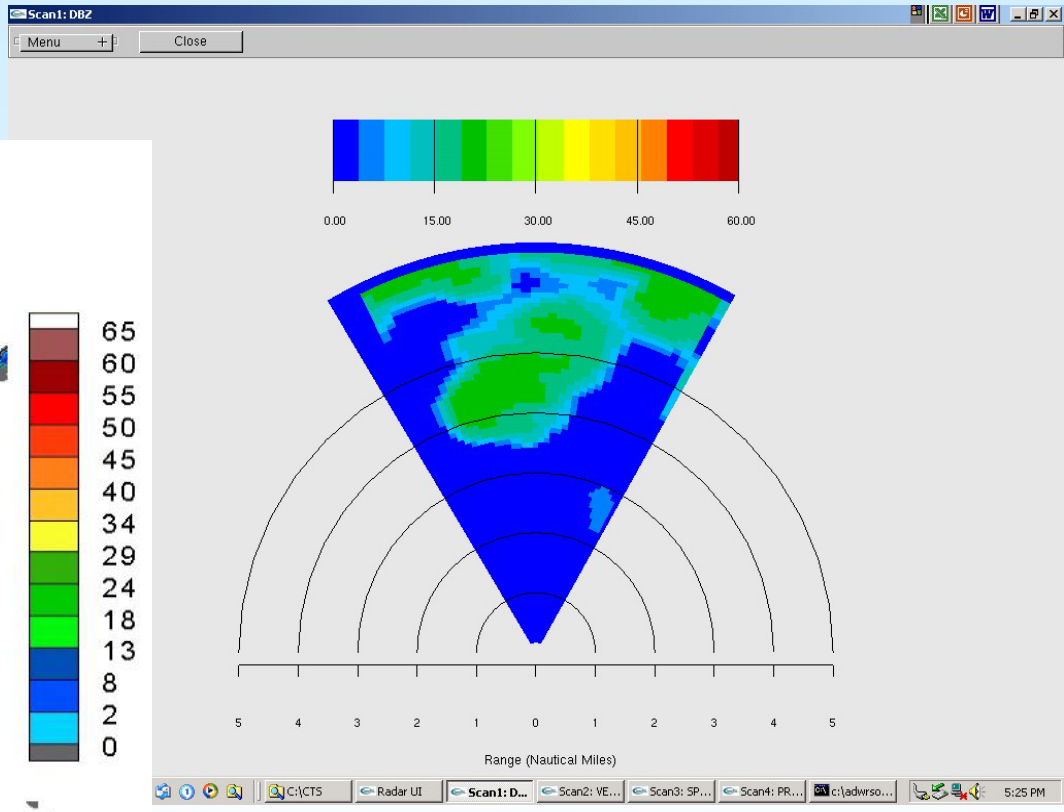
NASA Flight R-232, Event 10

- **NASA's B-757 on April 2002**
  - **Altitude = 10 km**
  - **Airspeed = 235 ms^{-1}**
  - **Weight = 178 klbs**
  - **Flight path from south to north through low reflectivity storm top**
  - **Severe turbulence predicted**

232-10 Radar Reflectivity

Data Set



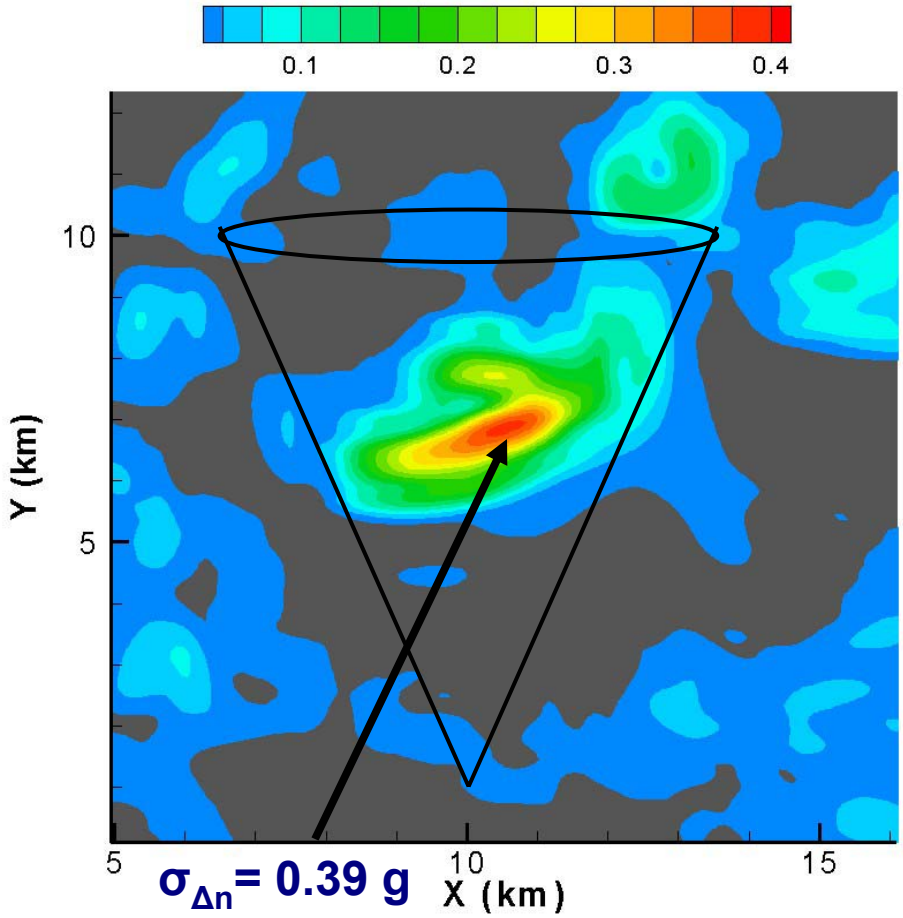


ADWRS Simulation

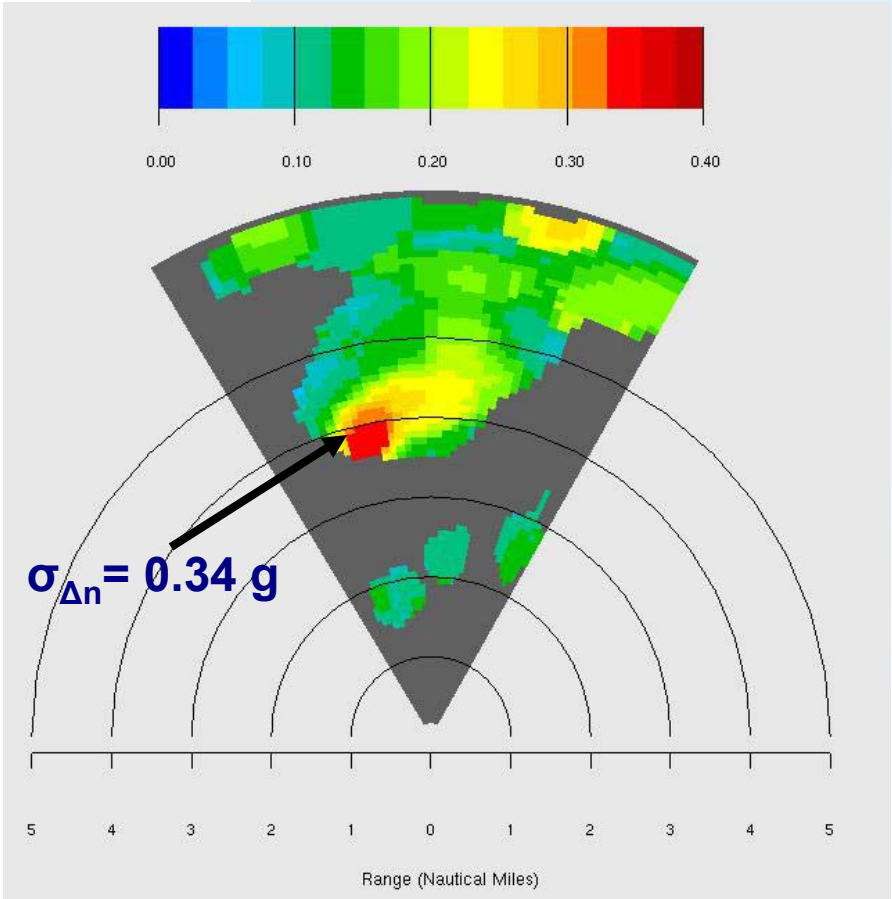
FHP/DWH

232-10 Hazard

Box Method



ADWRS/NESPA



FHP/DWH

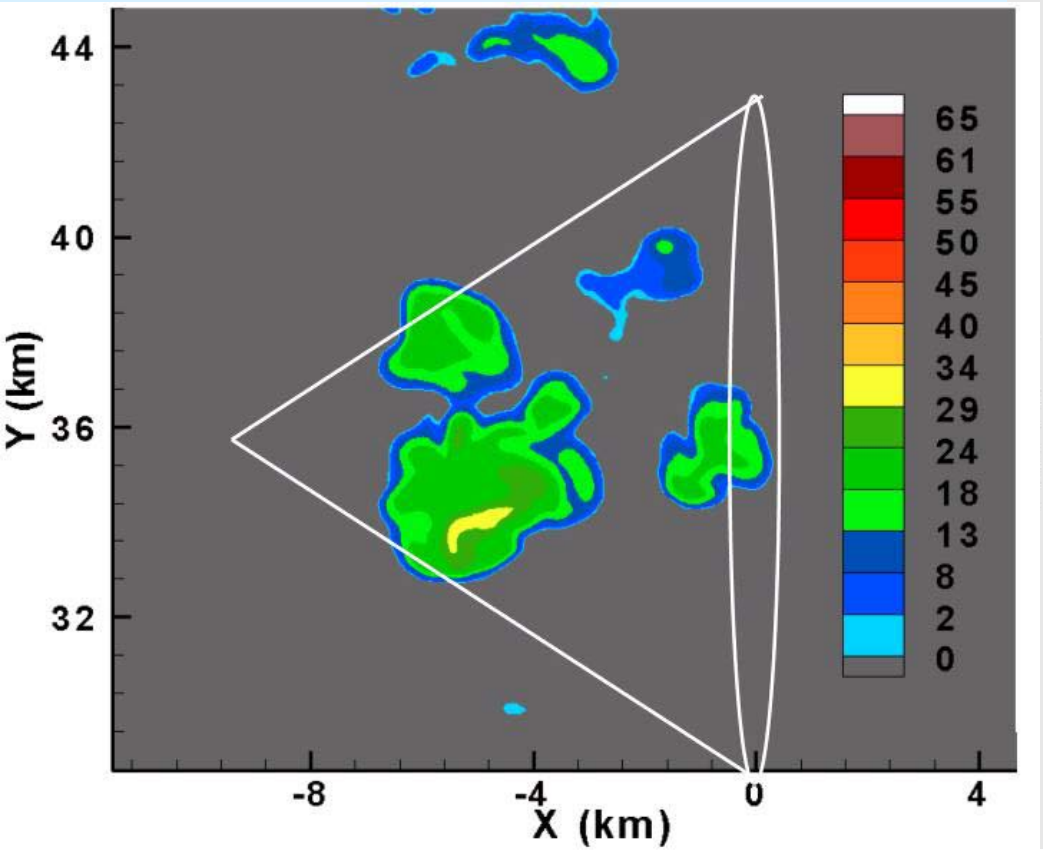
NASA Flight R-191, Event 6

- **Simulation with conditions during event**
  - **B-757**
  - **Altitude = 10.3 km**
  - **Airspeed = 235 ms^{-1}**
  - **Weight = 178 klbs**
  - **Data set representing low reflectivity, rising storm top**
  - **Moderate to severe turbulence predicted**

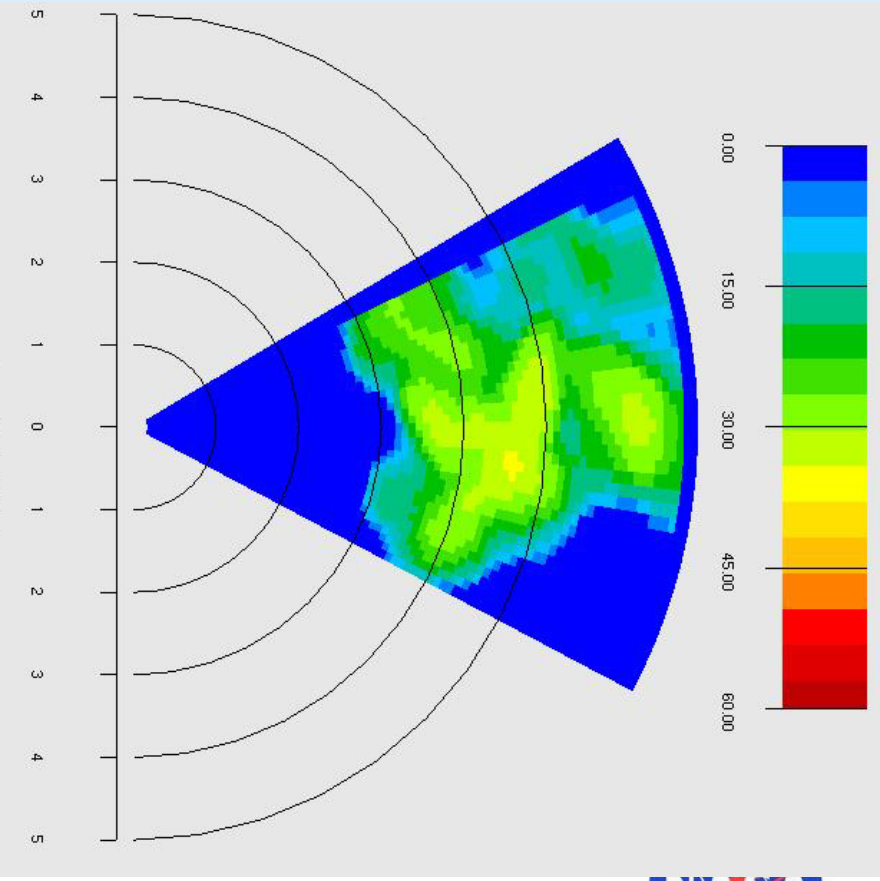
- **Sensitivity to Weight**

191-06 Radar Reflectivity

Data Set

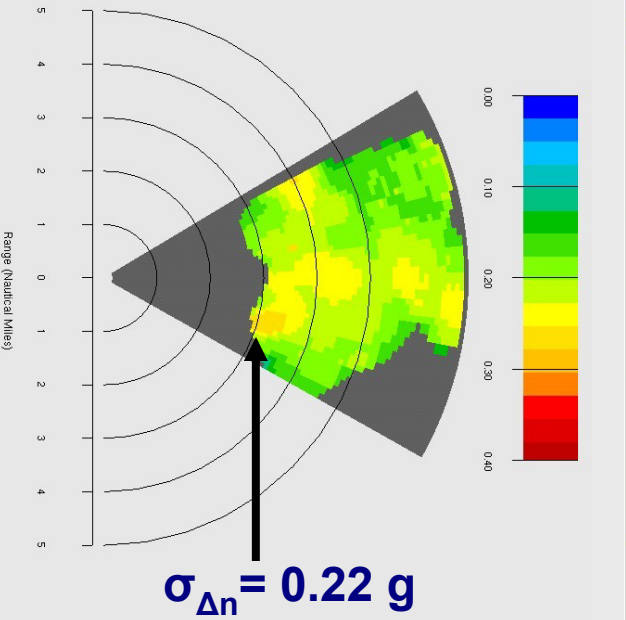


ADWRS Simulation



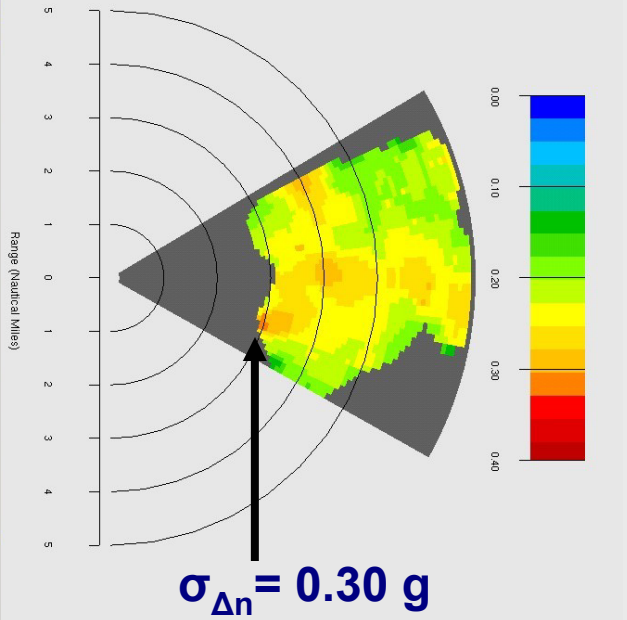
191-06 Hazard

Sensitivity to Weight assuming B-757



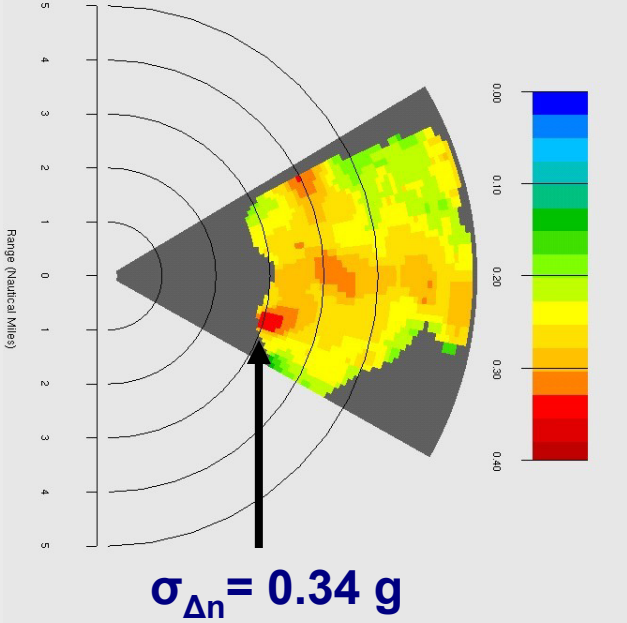
$\sigma_{\Delta n}$= 0.22 g

200 klbs



$\sigma_{\Delta n}$= 0.30 g

180 klbs



$\sigma_{\Delta n}$= 0.34 g

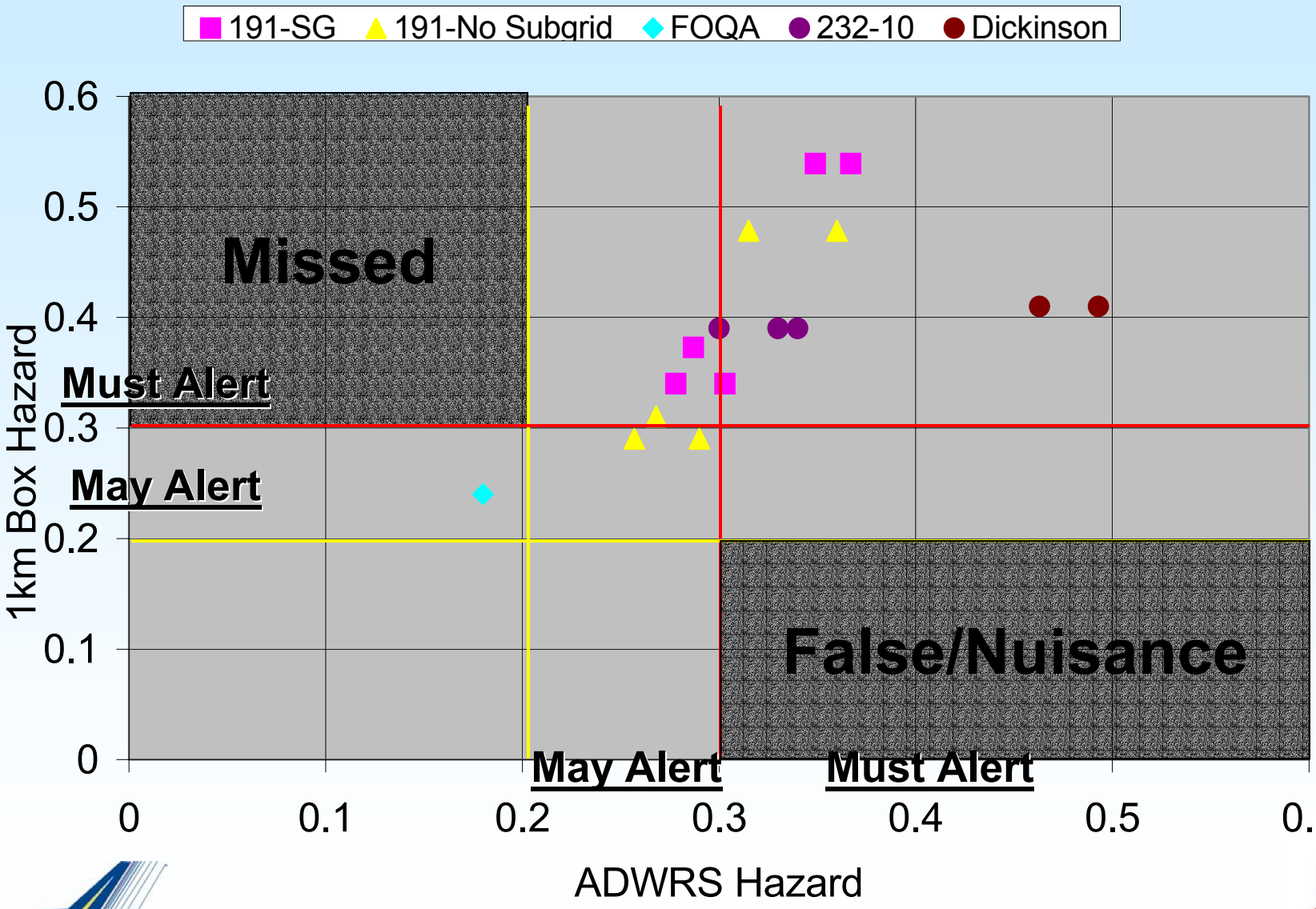
160 klbs

AVSP

NASA

FHP/DWH

RMS Load Comparison



SUMMARY

- **Tool set includes:**
  - **Data sets representing environments where aircraft encountered convectively-induced turbulence**
  - **Hazard metric algorithms for data set Analysis/Truthing**
  - **Hazard "Look Up" tables**
  - **Radar simulation system (ADWRS) to produce I&Q necessary for load predictions**
- **Tools for evaluating turbulence detection systems**

SUMMARY (cont.)

- ADWRS functionality demonstrated
- Hazard predictions in general agreement with Moving Box method
- Magnitude hazard sensitivity to aircraft type and weight
  - Heavily loaded aircraft less susceptible to turbulence than lightly loaded
  - Sensitivity to weight more significant than sensitivity to aircraft type

End of Presentation
?????'s

The following are extra slides

TPAWS Tool Set

- **Tool Set Components are Available at:**

  http://tpaws.larc.nasa.gov

- **Data Sets w/ Documentation**
  - **ADWRS**
  - **Hazard Tables**
  - **Previous Workshop Presentations**

References

[most available at http://techreports.larc.nasa.gov/ltrs/ltrs.html/ **and http://tpaws.larc.nasa.gov/]**

Case 191-6:

Proctor, F.H., D.W. Hamilton, and R.L. Bowles, 2002: Numerical Study of a Convective Turbulence Encounter. 40th Aerospace Sciences Meeting & Exhibit, 14-17 January, Reno, NV, AIAA Paper No. 2002-0944, 12 pp.

Proctor, F.H., D.W. Hamilton and R.L. Bowles, 2002: Numerical Simulation of a Convective Turbulence Encounter. Preprints 10th Conference on Aviation, Range, and Aerospace Meteorology, 13-16 May, Portland, Oregon, Amer. Meteor. Soc., 41-44.

Cases 232-10 and FOQA:

Hamilton, D.W. and F.H. Proctor, 2003: An aircraft encounter with turbulence in the vicinity of thunderstorm. 21st AIAA, Applied Aerodynamics Conference, 23-26 June, Orlando, Florida, AIAA Paper No. 2003-4075, 11 pp.

Dickinson:

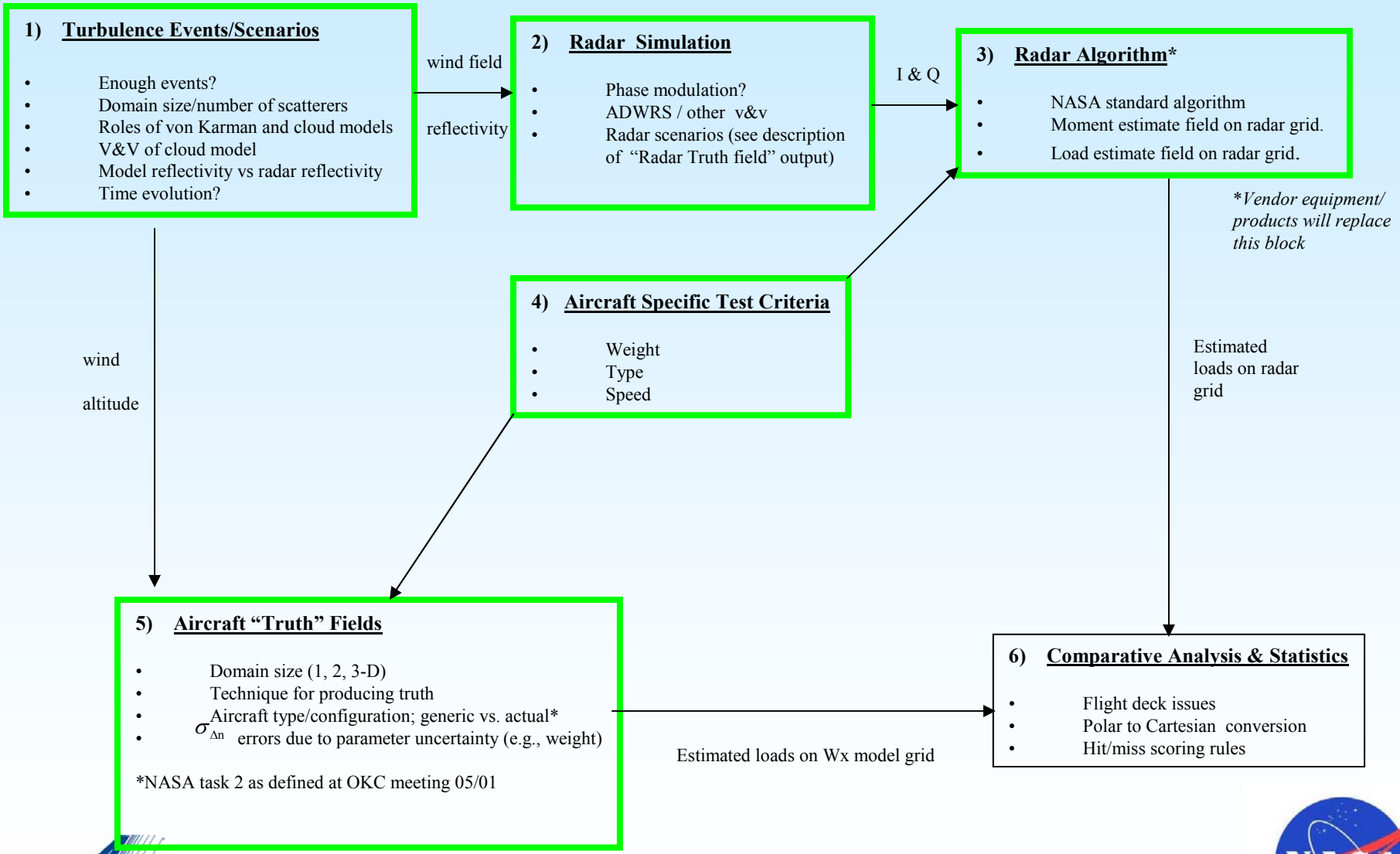
Lane, T. P., R. Sharman, and T. L. Clark, 2002: A Modeling Investigation of Near-Cloud Turbulence. Preprints, 10 th Conference on Aviation, Range, and Aerospace Meteorology, American Meteorological Society, Portland, OR, May 13-16, pp. 364-366.

Flight Tests:

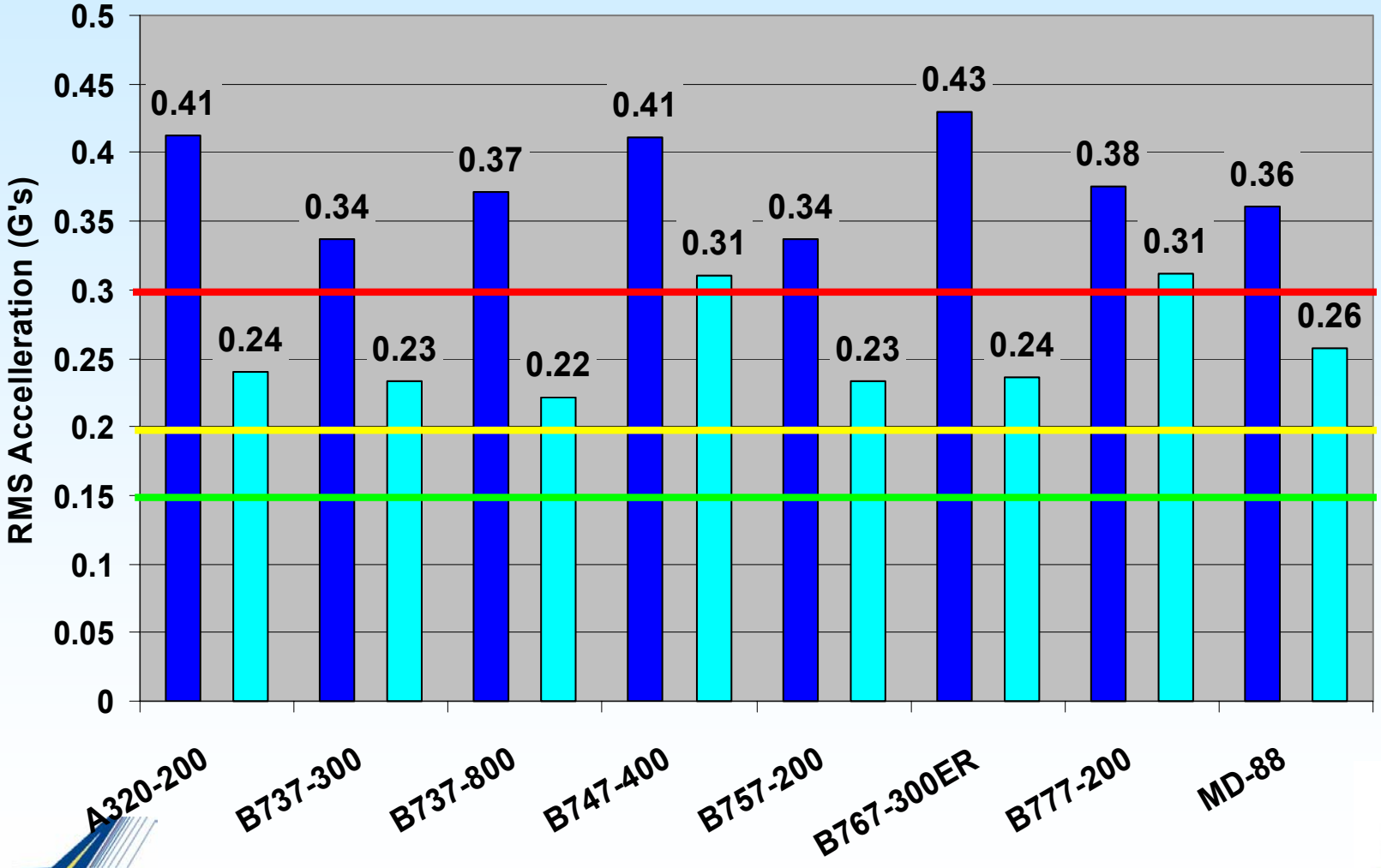
Hamilton, D.W., and F.H. Proctor, 2002: Meteorology Associated with Turbulence Encounters during NASA's Fall-2000 Flight Experiments. 40th Aerospace Sciences Meeting & Exhibit, 14-17 January, Reno, NV, AIAA Paper No. 2002-0943, 11 pp.

Hamilton, D.W., and F.H. Proctor, 2002: Convectively-Induced Turbulence Encountered During NASA's Fall-2000 Flight Experiments. 10th Conference on Aviation, Range, and Aerospace Meteorology, 13-16 May, Portland, Oregon, Amer. Meteor. Soc., 371-374.

Certification Methodology



Maximum Aircraft RMS G Based on Weight Variation
FLR 191-6 Data Set at 10.3 Km Elevation



AVSP

NASA

FHP/DWH